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INVESTIGATION OF MECHANICAL AND ELECTRICAL PROPERTIES OF KEVLAR/E-GLASS AND BASALT/E-GLASS REINFORCED HYBRID COMPOSITES

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ABSTRACT

Composite materials are preferred as an alternate for traditional metals due to its admirable properties like chemically inactive nature, high strength to weight ratio, ease of fabrication and capability of tailoring into the required shape. In order to apprehend the feasibility of Kevlar/E-glass and basalt/E-glass reinforced epoxy hybrid composites, this paper studies the low- velocity impact and flexural behavior and electrical conductivity of the composite laminates. Bend and impact test specimens were prepared as per ASTM 790 standard (80mm X 13mm X 3mm) and ASTM D256, ASTM D6110 standards respectively. The proportion of fiber and matrix material (75:25) is considered as an important factor for obtaining better flexural modulus. Izod and Charpy tests reveal that higher fiber volume fraction results in higher energy absorption. The hybrid composite combinations showed better electrical conductivity.

KEYWORDS: Impact Behavior, Flexural Behavior, Kevlar/E-Glass, Basalt/E-Glass, Hybrid Composite Laminates, Volume Fraction Hybridization & Electrical Conductivity

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Original Article

INTRODUCTION

Fiber reinforced polymer matrix composites are considered as the main alternate for the metallic materials due to its unique properties like cost economic nature, strength to weight ratio and lower density [1]. Carbon fiber plays a dominant role in the aerospace, automobile, marine, sports goods, and other industrial and construction applications over the past few decades due to its high fatigue resistance, chemical resistance, modulus and thermal insulation [2]. Even though carbon fiber has all superior properties over other traditional fibers its applications is limited in the industries due to its brittleness, high electrical conductivity, high cost and catastrophic failure over impact load [3]. Basalt, kevlar and glass fiber reinforced hybrid composites are purposefully used by the engineering industries to meet out the increasing demand of advanced materials.

There are the variety of materials and procedures available to produce tailor-made fiber reinforced composites but for developing composites for specific area or application the developer should familiar with materials and its properties over various circumstances [4]. The designer should conduct various experiments and

numerical studies to analyze mechanical properties of material [5].

The strength of the fiber reinforced polymer matrix composites depends on the mixing proportion of matrix and fiber material. Matrix is the main ingredient that joins all fibers together and evenly distributes load among reinforced fiber layers [6].

Kevlar is a most commercial man-made synthetic fiber used for making specific engineering materials were high impact resistance and flexibility is needed. The sheet or fabric of kevlar fiber contains aromatic polyamide structure [7]. E-glass fibers are famous reinforcement for fabricating hybrid composites. It has high electrical resistance and modulus. Basalt rock is processed at 1300-1700 °C for fabricating basalt fibers. Filament winding method is preferably used for basalt fiber production. Over two decades basalt fiber is used as an economical alternate for carbon fiber due to its high chemical, abrasion, thermal resistance and strength to weight ratio [8].

From the literature, it was observed that carbon fiber or glass fibers are combined with kevlar fiber to fabricate hybrid composites. Presently basalt fibers gained special attention as a replacement of glass and carbon fiber due to its increased physical, chemical and thermal properties. Basalt fibers are also used as temporary patches in the repair of carbon fibers [9].

Though, epoxies are used as insulators in electrical machineries, switchgears and transformers [10]. The free charge carrier's presence is very low in concentration; this makes it unsuitable for electronic equipment [11]. In order to achieve different conductivity ranges, epoxies are added with reinforcements for a variety of mechatronics applications.

Mechanical and electrical characterization is an important milestone in the process of developing new products or novel material for specific industrial application. The present investigation focuses on the study of low-velocity impact and flexural properties of polymer matrix composites reinforced with Kevlar/E-glass and basalt/E-glass fabrics. The fiber fabrics are two dimensional plain woven fabrics (2D-P). Two types of hybrid laminates (Kevlar/E-glass and basalt/E-glass) with sixteen layers of fibers in each laminate were fabricated with Vacuum assisted resin transfer molding process (Vacuum bag molding). In order to evaluate the effect of hybridization on mechanical properties such as static low-velocity impact and flexural behavior and electrical conductivity tests [12].

EXPERIMENTAL

MATERIALS

A matrix material epoxy resin is supplied by CF composites (Maharashtra-Mumbai), was used as polymer bi-component. Preferably, LY 556 epoxy base (density-1.32 g cm^3, viscosity-1450 MPa) and W152 LR resin hardener (density-0.90 g cm^3, viscosity- 32 MPa). Epoxy and hardener mixed in the ratio of 100/30. Kevlar, basalt and E-glass woven fabric with the areal density of 220 gm^2 were utilized as reinforcement [13]. Table 1 shows the composition of fibers and matrix materials used in this research.

Table 1: Composition of Fiber

S. No	Reinforcement	Volume Fraction
1	Kevlar/E-glass	75%
2	Basalt/E-glass	75%

All the three fabrics are plain were basalt and Kevlar fiber is provided by Hindustan composite solutions Mumbai-India and E-glass fabrics were supplied by Covai Seenu and Company, Coimbatore, Tamil Nadu-India. The property details of basalt, Kevlar and glass fabrics are shown in table 2 [14, 15].

Table 2: Properties of Fiber

Fiber	Tensile Strength (MPa)	Elastic Modulus (GPa)s	Specific Gravity	Max Temperature of Application (^{o}C)	Elongation at Break (%)
Basalt Fiber	3000-4840	93-110	2.65-2.8	650	3.1 -6
Kevlar Fiber	2900-3450	230-800	1.75-1.95	400	0.5-1.5
E-Glass Fiber	3100-3800	72.5-75.5	2.5-2.62	380	4.7

Laminates Preparation

The composites were fabricated by using vacuum assisted resin transfer molding process (Vacuum bag molding). Epoxy resin LY 556 and hardener W152 LR are premixed and homogenized at the ratio of 3:1. Volume fraction calculations were made by the following formulae [16],

$$\mathrm{Vf} = \frac{\mathrm{Wf}/\rho \mathrm{f}}{\mathrm{Wm}/\rho \mathrm{m} + \mathrm{Wf1}/\rho \mathrm{f1} + \mathrm{Wf2}}$$

Where, V_f= $Fiber\ Volume\ Fraction$, W_f= $WeightfractionofFiber$, ρ_f = $DensityofFiber$, W_m = $Weight\ of$ $Marix$, ρ_m = $DensityofMatrix$, W_{f1} = $Weight\ fraction\ of$ 1$st\ Fiber$, ρ_{f1} = $Density\ of$ 1$st\ Fiber$, $W_{f1,2}$ = $Weight$ $fraction\ of$ 1st and 2$ndFiber$

In this present investigation, two fiber laminates in the combination of kevlar/glass and basalt/glass were fabricated. In kevlar/E-glass Laminate ware arranged in the order of KK-GG-KK-GG-KK-GG-KK-GG. Similarly in basalt/E-glass laminate fabrics were stacked in the sequence of BB-GG-BB-GG-BB-GG-BB-GG. All the stacking sequences were considered symmetric about the neutral axis with the plate size of 300mm x300mm [17]. Finally, the plates were cut into the required specimens by waterjet machining process and edge surface was smoothened. The fabricated hybrid laminates are shown in figure 1 (a and b)

(a) **(b)**

Figure 1: Fabricated Hybrid Laminate:
a) Kevlar/E-Glass Laminate;
b) Basalt/E-Glass Laminate

Characterization

The modulus and stress-strain relationship of kevlar/E-glass and basalt/E-glass fiber laminates were obtained by performing flexural three-point bending test. The specimens were prepared as per ASTM 790 standard with the dimension of 80mm x 13mm x 3mm. Tests were carried out an universal testing machine (Instron 4486) having cross head speed of 4 mm/min. The maximum amount of energy required to break the specimen was determined by impact tests. Izod and Charpy low-velocity impact tests for the unnotched specimens were performed by using AIT-300N pendulum impact testing machine with a striking velocity of 5.6 m/sec, striking hammer weight of 18.7 kg and 1600 mm of pendulum swing diameter [18]. The test specimens are prepared as per ASTM D256 (Izod test), ASTM D6110 (Charpy Test) standards. In each hybrid laminates, three specimens were tested and the mean value of energy absorption is reported [19].

The electrical resistivity was studied by preparing the samples (60 x 6 mm) according to ASTM-F43-99 standard. Conductive silver epoxy was used to glue the aluminum electrodes and cured for 24 hrs to measure the resistance. Resistivity was measured using the equation

$$\rho = R \times (A / L)$$

Where ρ is the resistivity in Ωm, R is resistance in ohms, A is the area in m^2 and L is separation length between the two electrodes in m.

RESULTS AND DISCUSSIONS

Impact Test

The Charpy impact strength of Kevlar/E-Glass and Basalt/E-Glass composite laminates is shown in Table 3.

The impact strength of Kevlar/E-Glass reinforced laminates shows high resistance than Basalt/E-glass laminate.

Table 3: Charpy Impact Test Results

Hybrid Laminate	Charpy Test Specimens	Energy Absorbed in Joules	Average Energy Absorption in Joules
Kevlar/ E-Glass	1	6	5.66
	2	6	
	3	5	
Basalt/ E-Glass	1	3	4.33
	2	6	
	3	4	

Comparison of energy absorption of hybrid laminates shows kevlar(KK-GG-KK-GG-KK-GG-KK-GG) hybrid composite absorbs 23% higher impact energy than Basalt (BB-GG-BB-GG-BB-GG-BB-GG) hybrid laminates. Incorporation of glass fiber with kevlar and basalt fiber shows considerable changes in the mechanical properties of hybrid laminates because E-Glass is a precise reinforcement for fabricating hybrid composites with high modulus [15].

The energy absorption values of both kevlar and basalt hybrid laminates were calculated by Izod impact tester and results are shown in Table 4. The results displays that kevlar hybrid composites have high impact strength than basalt composite laminates this effect is due to the interfacial bonding between kevlar and E-glass is remarkably high.

Table 4: Izod Impact Test Results

Hybrid Laminate	Izod Test Specimen	Energy Absorbed in Joules	Average Energy Absorption in Joules
Kevlar/ E-Glass	1	10	10.66
	2	11	
	3	11	
Basalt/ E-Glass	1	9	9.33
	2	10	
	3	9	

Kevlar/E-Glass laminate has 12% more impact energy absorption nature than basalt laminates. The volume fraction between matrix and reinforcement also plays important role in the determination of mechanical properties of hybrid laminates. Generally, higher reinforcement possesses greater mechanical properties.

Flexural Test

The figure 2-5 shows relationship exhibits between force vs. displacement and stress vs. strain curves for the Kevlar /E-glass and Basalt /E-glass respectively: Kevlar configuration high flexural strength than basalt configuration it is noted that adding 75% volume fraction of glass fiber with Kevlar shows that flexural strength is twice the basalt/E glass laminate.

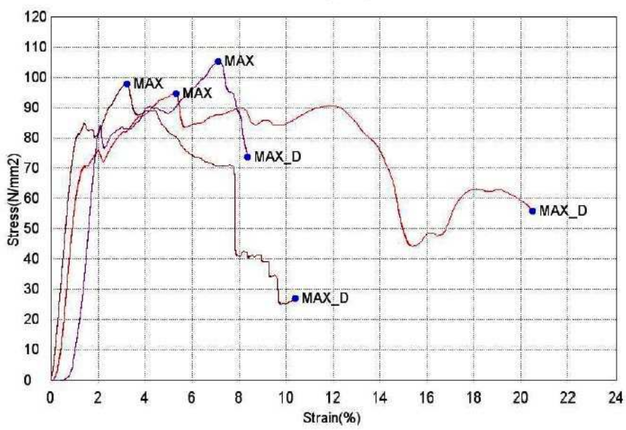

Figure 2: Stress vs. Strain Curve -Basalt /E-Glass Laminate

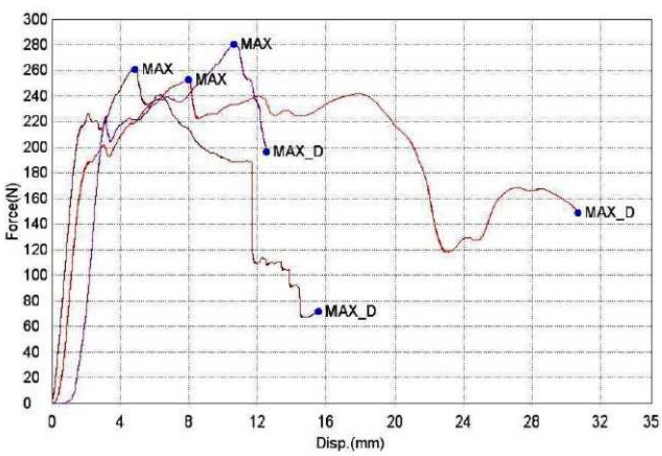

Figure 3: Force vs. Displacement Curve - Basalt /E-Glass Laminate

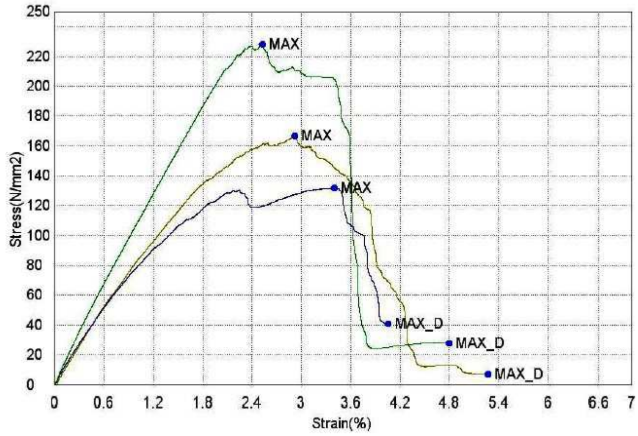

Figure 4: Stress vs. Strain Curve-Kevlar/E-Glass Laminate

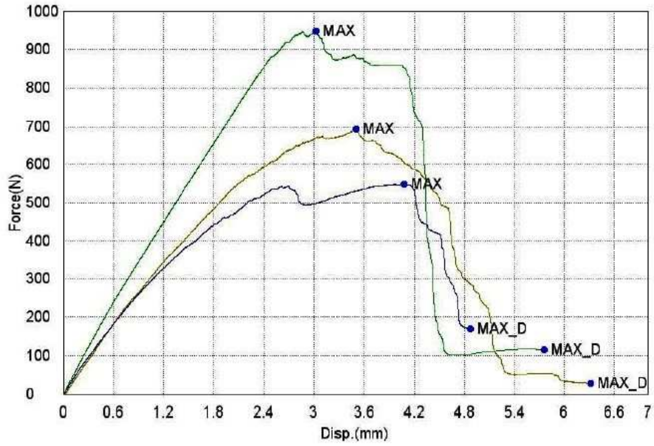

Figure 5: Force vs. Displacement Curve -Kevlar/E-Glass Laminate

The results of this research confirm the effect on the mechanical properties. The results report that coefficient of variation of kevlar composite is moderate in the 3 points flexural test, this is because there are no discontinues phase and the resin distribution is even. When as in basalt laminates coefficient of variation is very high due to high interlaminar shear stress. It indicates that Kevlar fiber has better coordination with E-Glass fiber than basalt fiber.

Electrical Resistivity Results

The electrical resistivity was measured to quantify the electrical conductivity. Table 5 shows the measured values of electrical conductivity.

Table 5: Electrical Resistivity Values for Basalt /E-Glass Laminate and Kevlar /E-Glass Laminate

Sample	Resistance (Ω)	
	Trial 1	Trial 2
Basalt /E-Glass laminate	17	16
Kevlar /E-Glass laminate	13	15

Kevlar /E-Glass laminate sample showed the highest conductivity (or least resistivity) than Basalt /E-Glass laminate. The Kevlar /E-Glass laminate showed 17 % improved conductivity. The conductivity in the composite samples increase was due to activation energy that decreases with the presence of Kevlar /E-Glass and Basalt /E-Glass fibers and the dielectric constant decreases with the increase in frequency

CONCLUSIONS

Epoxy based Polymer matrix fiber reinforced hybrid composite laminates were fabricated successfully (Vacuum Assisted Resin Transfer Molding) by combining Kevlar/E-Glass and Basalt/E-Glass fibers and laminate configurations. The prepared hybrid laminations were characterized to study flexural and impact strength. Volume fraction plays a major role on the flexural strength of hybrid composites, Kevlar/E-glass combination reported good flexural strength. Kevlar/E-glass laminates composite revealed high impact strength for both Izod and Charpy tests. Kevlar/E-Glass laminates showed high impact energy absorption and crack propagation resistance, enhanced damage tolerance and delamination without catastrophic failure. The electrical conductivity of Kevlar /E-Glass laminate samples showed the highest.

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